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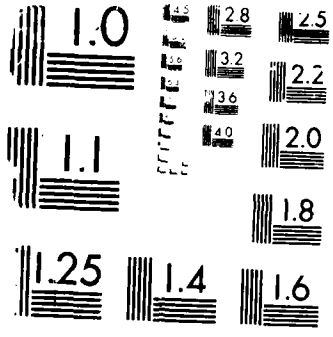

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The outputs of the ARO sponsored activity have been seven research manuscripts, two masters theses and two software packages. (abstract continued on next page)

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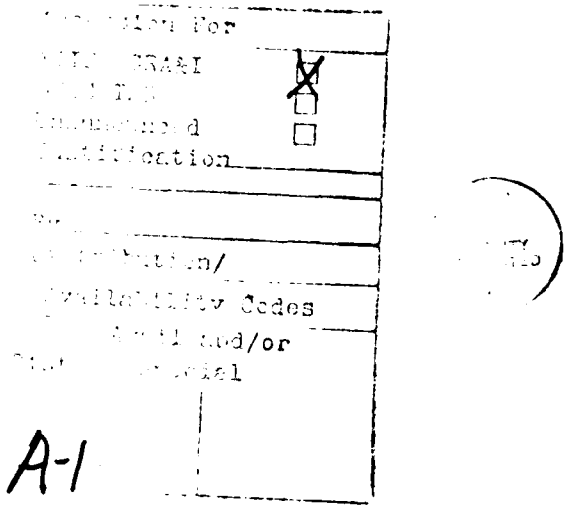
20. ABSTRACT CONTINUED

Cameron (1986) and Ball and Cameron (1986) describe efficient data structures and graph search strategies for implementing network reliability analysis algorithms. These were used to develop NETREL, which solves 2-terminal and all-terminal network reliability analysis problems. It is written in Pascal and has been run on IBM micros and mainframes. The computation times for various test graphs appear to be the best published in the open literature to date. These algorithms and their implementation in NETREL should be very useful in the analysis and design of a variety of communications networks. They determine the overall reliability of the network given the reliabilities of its components (nodes and links).

The main theoretical results produced by this project involved an analysis of the union of products problem. The union of products problem uses a system representation consisting of a list of pathsets or a list of cutsets.

Ball and Provan (1986) and Provan and Ball (1986) provide a complexity analysis of the problem, give general bounding algorithms and demonstrate certain solvable cases. Furthermore, they make contributions to the general body of knowledge on matroids and 2-monotonic systems.



FINAL REPORT: A COMPUTER CODE FOR THE SOLUTION OF LARGE SCALE NETWORK RELIABILITY ANALYSIS PROBLEMS

A RESEARCH PROJECT FUNDED BY THE U.S. ARMY RESEARCH OFFICE

ARO PROPOSAL NUMBER 20664-MA

APRIL 1985 - OCTOBER 1987

by

Michael O. Ball
College of Business and Management
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College Park, MD 20742

During this project a number of topics in the area of combinatorial and network reliability were investigated. This research resulted in both new theoretical advancements and practical reliability analysis and optimization software.

For reliability purposes a system consists of a set of components which are organized into a particular structure. Individual components can fail and certain combinations of component failure can lead to the failure of the system. For reliability analysis problems, we are given the set of components together with failure probabilities for each component and the definition of the system's structure, i.e. the manner in which the components are interconnected to form the system. The reliability analysis problem is then to compute the failure probability of the system. For reliability optimization problems, we are given the above information together with component costs. Two classes of reliability optimization problems can then be defined. The first is to maximize system reliability subject to a budget constraint and the second to minimize cost subject to achieving a minimum level of system reliability. All of the above problems are important in the design of reliable systems. With a reliability analysis algorithm at hand, the designer would propose a number of designs and then use an analysis algorithm to evaluate and choose from the set of potential designs. An optimization algorithm would allow the designer to consider implicitly a much wider class of potential designs.

The outputs of the ARO sponsored activity have been seven research manuscripts, two masters theses and two software packages. A large part of the work has been completed on a third masters thesis as well. The completed documents and software packages are listed at the end of this report. Cameron (1986) and Ball and Cameron (1986) describe efficient data structures and graph search strategies for implementing network reliability analysis algorithms. These were used to develop NETREL, which solves 2-terminal and all-terminal network reliability analysis problems. It is written in Pascal and has been run on IBM micros and mainframes. The computation times for various test graphs appear to be the best published in the open literature to date. These algorithms and their implementation in NETREL should be very useful in the analysis and design of a variety of communications networks. They determine the overall reliability of the network given the reliabilities of its components (nodes and links).

The main theoretical results produced by this project involved an analysis of the union of products problem. The union of products problem uses a system representation consisting of a list of pathsets or a list of cutsets. A pathset is a set of components whose operation implies system operation with the additional property that no subset of the set also satisfies this

condition. A cutset is defined analogously relative to component and system failure. Pathset and cutset representations are typically used in the analysis of systems having representations more complex than networks, e.g. fault trees. The union of products problem is to determine the value of system reliability given a list of pathsets or cutsets and given the reliabilities of the individual components. Ball and Provan (1986) and Provan and Ball (1986) provide a complexity analysis of the problem, give general bounding algorithms and demonstrate certain solvable cases. Furthermore, they make contributions to the general body of knowledge on matroids and 2-monotonic systems.

Ball and Provan (1986b) and Ramesh, Ball and Colbourn (1985) extend previous work of the principal investigator on network reliability problems. The work with Provan provided a means for the cut-based 2-terminal algorithm to be extended to k-terminal problems. The work with Ramesh and Colbourn described methods for strengthening the all-terminal network reliability bounds developed earlier by Ball and Provan.

Assad, Ball, Golden and Jeffs (1987), Ball and Jeffs (1987) and Jeffs (1987) all deal with a hierarchical approach to reliability analysis. The focus of this work has been the software package ACES (Availability and Cost Evaluation System). ACES is a micro-computer based tool that allows a system designer to interactively design a complex system using a hierarchical, top-down approach. Within this context it provides the user with system availability and cost information. Thus, the system designer can immediately see the effect of design changes on the overall system availability and cost. The development of this package, which we believe to be quite practical, required the solution of system design questions, some related to reliability analysis.

Recently, the principal investigator working with graduate student Li Liu developed dynamic programming reliability optimization algorithms and incorporated them into ACES. This second version of ACES allows a system designer to define design alternatives. Using dynamic programming, ACES then produces a an approximate set of efficient solutions. An efficient solution has the property that reliability cannot be improved without increasing cost and cost cannot be reduced without degrading reliability. A set of efficient solutions generated under the proper conditions contains solutions to both the optimization problems mentioned above.

Manuscripts and Theses

Assad, A., M. Ball, B. Golden and V. Jeffs, 1987, "An Interactive Tool for Reliability Analysis on a Microcomputer", to be published in American Journal of Mathematical and Management Sciences.

Ball, M. O. and E. Cameron, 1986, "Experiments with Network

Reliability Analysis Algorithms", in Modeling and Simulation: Proceedings of the Seventeenth Annual Pittsburgh Conference, W. G. Vogt and M. H. Mickle eds., **17**, 1799-1803.

Ball, M. O. and V. Jeffs, 1987, "ACES: A System Structure, Cost and Reliability Design Tool", presented at IBM Academic Information Systems University Conference, Boston, June 1987.

Ball, M. O. and J. S. Provan, 1986, "Disjoint Products and Efficient Computation of Reliability", to be published in Operations Research.

Ball, M. O. and J. S. Provan, 1987, "Computing K-Terminal Reliability in Time Polynomial in the Number of (s,K)-Quasicuts", Transactions of the Fourth Army Conference on Applied Mathematics and Computing, 901-907.

Cameron, E., 1986, Efficient Implementation of Network Reliability Analysis Algorithms, MS Thesis, Department of Management Sciences, University of Waterloo.

Jeffs, V., 1987, "Availability and Cost Evaluation System for Micro-Computers", MS Thesis, College of Business and Management, University of Maryland at College Park.

Provan, J. S. and M. O. Ball, 1986, "Efficient Recognition of Matroids and 2-Monotonic Systems", to be published in Proceedings of Third SIAM Conference on Applications of Discrete Mathematics.

Ramesh, A., M. Ball and C. Colbourn, 1985, "Bounds for All-Terminal Reliability in Networks", Annals of Discrete Mathematics, **33** 261-273.

Software Developed

ACES -- Availability and Cost Evaluation System

(version 1): Interactive software package for performing a top-down systems design; during the design process, the user receives continuous feedback as to the impact on system cost and system availability of any design decisions made; written in Pascal and Assembler, runs on IBM PCs and compatibles; developed by Vince Jeffs.

(version 2): Includes all of the features of version 1, together with optimization capabilities; the optimization modules employ dynamic programming to produce a set of efficient solutions; each efficient solution produced has the property that system cost cannot be reduced without degrading system availability and system availability cannot be improved without increasing system cost; the user can choose among the efficient solutions to

maximize availability subject to a budget constraint or minimize cost subject to an availability constraint; developed by Li Liu.

NOTE: ACES, version 2, together with a users manual will be delivered to ARO shortly.

NETREL -- NETwork RELiability Analysis System

Efficient software for computing 2 and all terminal directed network reliability analysis; written in Pascal, runs on IBM PCs and compatibles as well as certain mainframes; developed by Erin Cameron.

Personnel Supported

Michael O. Ball, principal investigator, Associate Professor, University of Maryland at College Park.

Erin Cameron, MS, Department of Management Sciences, University of Waterloo, 1986.

Vincent Jeffs, MS, College of Business and Management, University of Maryland at College Park, 1987.

Li Liu, MS, College of Business and Management, University of Maryland at College Park -- expected in 1988.

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